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Sustainable Performance of Diverse Regional Vernacular Architecture of India – case study of I. G. R. M. S. Bhopal, INDIA

Sanmarga Mitra[a*], Dr. Shivashish Bose[b]

[a]*Assistant Professor, School of Planning and Architecture, Bhopal, 462030, INDIA*
[b]*Professor, Department of Architecture, Jadavpur University, Kolkata, 700032, INDIA*

Abstract

India is a large subcontinent having many diverse regions, each having its own vernacular architecture tradition. These regions are as diverse as hills, desert, coastal area, hot and humid riverine plain, humid rainforests and many more. Similarly, the vernacular forms of architecture are diverse in their layout, form, building materials, methods of construction and structural systems. There is but one basic similarity – they are climatically and geographically most suited to their original regional location.

Indira Gandhi Rashtriya Manav Sangrahalaya (IGRMS), Bhopal is a museum that houses examples of these vernacular structures in full scale built by their original inhabitants in natural site. The city of Bhopal is capital of the state of Madhya Pradesh (literally translates as the Central Province, and justifies that name with its central position in India) is situated 'Humid Sub-tropical' region of India as per Koppen's classification and offers a different context from the original site and climate situation of these vernacular structure.

This paper thus aims at assessing whether and how vernacular architecture performs consistently in regions other than its own when transplanted. Thus, it has recorded and quantified climatological data for some of these vernacular huts belonging to diverse regions to compare and contrast their construction material, design and thermal performances on a iso-climatic framework. In the research, climatic data like ambient temperature, wind velocity, relative humidity have been collected for selected vernacular houses that are originally scattered within the huge geographical area of India, and which also belong to varied climatic regions. These houses vary in terms of their layout, materials and methods of construction and so forth. These data have been compared and analysed to find their dependence on the different building features and components of these houses. The analysis of the collected database have also been used to assess the basic question of the research i.e., to assess and compare the relative performance of these houses brought together in a single place under the same climate.

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Keywords: Vernacular architecture, climatic data, comparison of thermal performance, climatic regions

* Corresponding author. Tel.: +91-7869556494.
E-mail address: smitra@spabhopal.ac.in

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1. Introduction, Aim and Objective

India is a large subcontinent having many diverse regions, each having its own vernacular architecture tradition. The museum named Indira Gandhi Rashtriya Manav Sangrahalaya at Bhopal, India showcases these diverse examples of vernacular architecture as full scale buildings built by the tribal people to whom these structures originally belong to. These structures hail from regions as diverse as hilly region, desert area, coastal area, hot and humid riverine plain and may more. Although they are climatically and geographically most suited to their original context, there remains a question as to how well they may perform when transplanted to an alien region.

This paper aims at assessing whether vernacular architecture performs consistently in regions other than its own when transplanted. Thus, it has the objective to record climatological data for some of these vernacular huts belonging to diverse regions to compare and contrast their construction material, design and thermal performances on a iso-climatic framework.

2. Scope and limitation

The scope of the paper allows us to work within the existing setup that the IGRMS museum provides in terms of the full scale exhibits. However, a limitation of the analysis is that it does not allow on-site simulation of huts in terms of their varying orientation. Another limitation was that it was not possible to inspect the actual material and method of construction of the buildings, for which secondary data in terms of interview of museum officials was the only available source.

3. Methodology

The methodology of the paper is as follows:

Introduction of the research project

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Identification of typical features and components of Indian vernacular architecture from literature survey and field study

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Enlisting of features of vernacular architecture that contribute to its thermal performance

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Study and documentation of selected vernacular houses from IGRMS, Bhopal

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Collection of climatic data on temperature, wind velocity and RH, on houses under study

↓

Analysis of collected data

↓

Inferences

↓

Conclusion

4. Introduction – vernacular architecture and regions of India

Vernacular architecture has various definitions given by academicians and experts from time to time. There are some common factors which surface out from among them though. Thus, vernacular architecture may be defined as buildings / structures that are

- Built by an ethnic community belonging to a specific region;
- Designed by community members who do not have any formal education in architecture or home building;
- Design of the structure considers local climate, culture, site context, specific family requirements and available materials;
- Built from locally available materials;
- Constructed through traditional skill and craft;
- Constructed by a participatory process in which the occupiers of the house as well as the entire community participates;
- Fosters traditional building and designing skills for future generation, and also nurtures their culture through built forms and decorations.

In the discussion of vernacular architecture, it is often intermingled with traditional or indigenous architecture. There is but a very thin line of difference between them – while traditional or indigenous architecture do have a strong involvement of qualified architects in them, vernacular architecture is devoid of any architect and is created with participatory design and construction of the occupiers of the house and their community members.

The above diagram shows vernacular architecture to be a result of the inter-action of four basic factors – site, climate, material and skill. Each of these vary widely from one region to other, especially in a vast country like India. Moreover, when we inspect these factors carefully, materials and (traditional) skill comes as a result of a regional context and its climate. It may be thus said that vernacular architecture should and actually varies from one climatic zone to the other.

As per Koppen's Classification of Climatic Zones, India is divided into various zones as shown in the following map:

These zones vary widely in terms of their climatic characteristics like diurnal temperature ranges, variation of relative humidity and movement of wind. Accordingly, the architecture of their vernacular huts cope up with the climate and geography and each tribe has its own architecture.

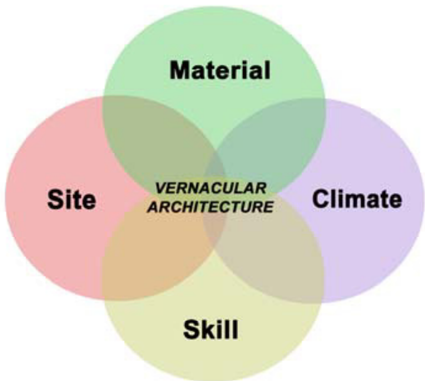

Fig. 1. Origination of Vernacular Architecture

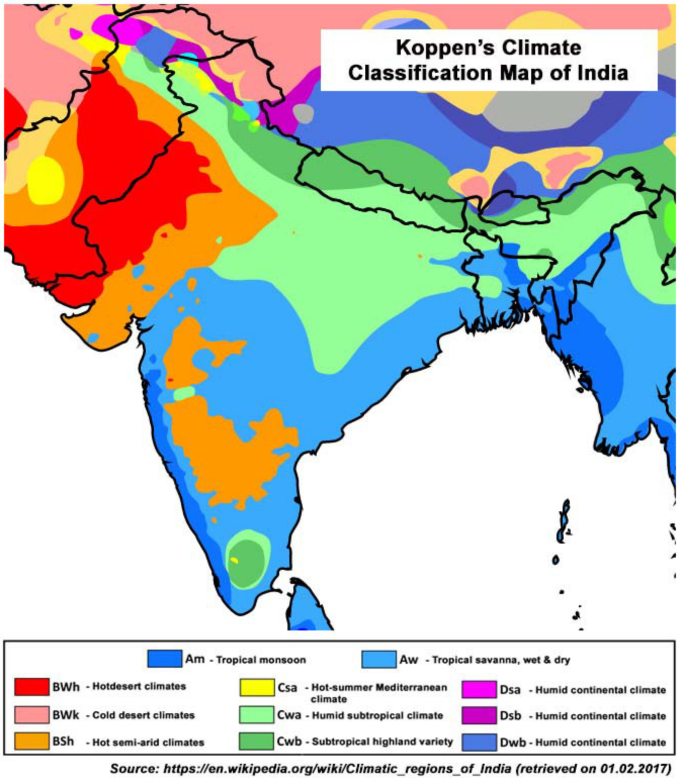

Fig. 2. Map of India showing
Koppen's Classification

5. Typical features and components of Indian vernacular architecture

Although Indian vernacular architecture is widely variegated in terms of their design and appearance, all of them have some common features which they share sometimes even with local traditional buildings.

These features, as we categorize them into groups of structural and/or architectural components, are –

- **Plinth / Platform** – the nomenclature vary depending on the material with which this is built, a plinth or a platform is essentially the lowest part of the vernacular hut. This raises the living plane in order to protect the inmates from hostile nature (flood, strong wind) or from unwelcome fauna (predating or venomous). It also often creates the building on a raised plane to protect the cattle stock under the main house, which in turn warms up the floor with the warmth of their body.

- **Vertical Support System** – all vertical load bearing posts made of various materials like bamboo, wood, stone would come under this category. They are the most vital member in the structure as most of the vernacular huts have sloped roof which rests on these posts.

- **Wall** – vernacular huts can be divided into two types as per the disposition of walls within them – (a) Huts with no partition and one single room, and (b) Huts compartmentalized into rooms / niches. They can further be divided into two types based on the transmission of load through the wall, viz, load bearing wall and non-load

bearing or skin wall. Walls in vernacular architecture are rarely made load bearing because of the wall's susceptibility towards natural forces of earthquake, flood, storms and the like.

It would be important to mention here that the wall and the vertical supports are sometimes detached from each other, unlike conventional architectural practice. The gap between the wall and roof serves the purpose of venting out the hot air and kitchen smoke.

- **Openings** – to maintain the thermal balance, vernacular huts have minimum possible openings. Apart from the doors, which in most cases are kept to the bare minimum of height, openings are rare in the huts from hot and dry regions as well as cold regions. On the other hand, huts from hot and humid regions need more openings for more ventilation – although they have to compromise on the size of openings for structural requirements.

- **Roof** – mostly sloped roof, they have covering of thatch, tiles, shingles or metal sheets on truss made of bamboo or timber. These roofs do not end at the edge of the wall and project out to a considerable extent creating large overhanging eaves that protect the wall from both sun and rain water. Although all roofs are sloped, their pitch varies according to the speed of wind they face, the highest temperature the region experiences and the nature of precipitation they would have to sustain.

- **Overhead Storage / Loft** – vernacular buildings from hot-dry and hot-arid parts of India relies more on overhead storage spaces to reduce the volume of interior space. This loft space also separates out the upper hot zone from the lower cool zone of the building.

6. Features of vernacular architecture that contribute to its thermal performance

According to Gupta & Chakraborty (2012), the features of vernacular architecture that categorically influence its thermal performance are as follow:

- **Orientation**: varied orientation of the same building yield different thermal conditions inside. This can be inferred as that the same wall design facing different sun angles would have different thermal conditions.

- **Building Material**: each building material has its own U value or rate of transmission of heat. Further, a composite of different materials would yield a new transmission rate. Extent of transmission can be ascertained by two facts – (i) the difference of temperature on the external and the internal surface, and (ii) the extent of time lag a house has.

- **Surface Area to Volume Ratio**: surface area of a building is directly proportional to the absorption of heat. In this context, openings are not considered as surface area as they transmit heat freely when they are open, and it becomes difficult as to how many hours they are being kept open during a study period.

- **Shading**: a building, which includes it external walls and its openings, may be shaded from sun and water with the help of its roof. In vernacular buildings with sloped roofs, overhanging eaves do this most efficiently.

- **Ventilation**: cross-ventilation within a building regulates the relative humidity within a building and thus regulates the climatic comfort level of the inmates. With the same internal temperature, varying levels of relative humidity may lower or elevate the comfort conditions. This factor would be particularly important for huts located in hot and humid climatic regions.

Along with this, other features that control the overall performance include Form and Massing, Spatial Organisation and Open – Built Distribution (Gulati & Pandya, 2014).

This paper intended to inspect thermal performance of vernacular huts on the above features, and at the same time investigated whether huts belonging to other regions perform satisfactorily in an alien environment.

7. Types of house studied in IGRMS, Bhopal and their brief descriptions

Indira Gandhi Rasthriya Manav Sangrahalaya (IGRMS), Bhopal is a museum with a rich anthropological collection. It has a dedicated section on tribal habitat comprising of both indoor displays as well as actual huts built in nature. There are at present 31 vernacular huts, each conceptualised and built by the tribes to whom they belong. These tribes remain responsible for the maintenance of these huts, and visit IGRMS from time to time for this purpose.

Considering the typical building components of Indian vernacular architecture and the features that influence thermal comfort in a vernacular building (as discussed under sections 4 and 5), five types of buildings have been chosen for study. These are:

1. Santhal House of Jharkhand
2. Garo House of Meghalaya
3. Muria Ghotul of Chhattisgarh
4. Rathwa Hut of Gujarat
5. **5.** Gadba Hut of Orissa

Two more sheds, built by the local Bhil tribe, and used for exhibitions of bullock carts and pottery workshop were also studied as examples of shelters without any skin wall and shelters enclosed partially.

Locations of these huts are shown below on the satellite imagery of the museum. Brief descriptions of these houses, along with their plans, are provided in the following discussion.

Fig. 3. Satellite image of IGRMS showing location of huts under study

7.1. Santhal Hut, Jharkhand

Santhals are ancient agrarian tribe of India and are settled in the eastern part of Chhotanagpur plateau. Because of their strong agrarian economy, they are quite financially well off among the tribes, which shows through the scale

and nature of their house. As farmers, bovine cattle stocks are very dear to them and occupy an important position in their house. The Santhal settlements in Jharkhand are mostly located along the border of West Bengal and Orissa, which has many earthen double storied buildings. However, most Santhal huts are single storied structures.

Fig. 4. Santhal House at IGRMS – (a) Plan of hut, (b) External view of hut, (c) (d) Views of internal courtyard, (e) Junction of roof and wall

The Santhal house studied here is a single storied building with square plan. In the centre is a courtyard that is open to sky. The entry into the building is flanked by the main habitation room and kitchen on one side and the cattle sheds on the other.

The house is built on a mud plinth. Walls are made of mud in adobe technique, i.e. mud stabilized blocks on split bamboo mats. The roof has a system of straw thatch placed on bamboo and wooden truss. Windows are minimum here in the living quarters; whereas the husking area as well cattle sheds have quite a number of openings in them.

7.2. Garo House, Meghalaya

The name of the state implies abode of clouds, and indeed the climate is predominated by incessant rainfall. Garo houses are therefore well equipped to take care of this. The terrain is hilly, with high temperature and excessive humidity during summer and monsoon times, and a very cold but damp winter.

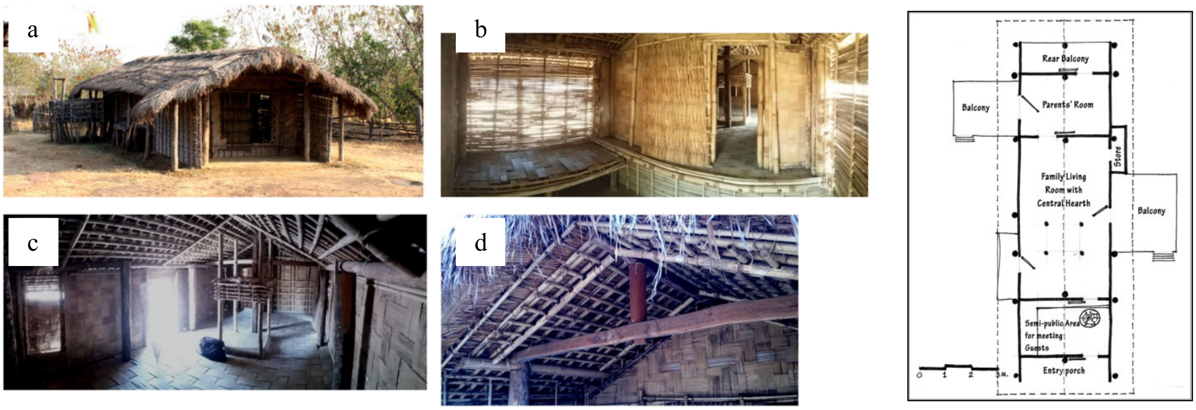

Fig. 5. (a) View of Garo House, (b) (c) Interior view of the hut, (d) Detail of roof, (e) Plan of Garo Hut

To build a level house on a contoured site and to protect it from unfazed runoff along the ground, Garo tribesmen build their house on stilts made of wooden poles. The floor is built on a framework of logs, with the finer infill done with narrow bamboos which are particularly available in this region.

The load bearing framework of the structure is made of timber poles. The wall is made of mats woven with thin bamboos with split bamboo strips. Garo artisans also device an unique way of creating bamboo mats – they split open the bamboo poles, flatten them with mallets and weave the mat with these flats.

The roof is thatch made from a local grass. They are quite particular about the grass, and have brought the original material all the way from Meghalaya to Bhopal for making the museum hut. The thatch is supported on bamboo purlins placed on timber trusses.

The layout of Garo hut is linear, with all the rooms laid on an axis without projecting out any mass whatsoever. There are some elevated balconies projected from the main living rooms that are open to sky.

7.3. Muria Ghotul (Community House), Chhattisgarh

Ghotuls are community houses or hostels of Muria villages. The adolescent youth of Muria population are required to stay in these hostels and partake training in their future endeavours. These trainings continue during entire day, whereas they participate in community singing and dancing during the evening in front of these Ghotuls. Muria social system allows a free mixed growth of different genders in these Ghotuls, and hence the space requirement of them is quite simpler than common houses.

Fig. 6. (a) Front view of Ghotul, (b) Rear view of Ghotul, (c) Interior view showing structural system

Originally Ghotuls were plain shaded areas having an earthen plinth and a sloped roof supported on timber poles and truss. In due course of time clay skin walls have been built inside the colonnades. This gives the structure an unexpected similarity with Greek pseudo-peripteral temple plans.

The mud wall is built by placing mud adobe blocks on bamboo mats. They stop short of the roof by a considerable margin (6” – 3 feet) and this allows proper ventilation of the room. The unpartitioned and un-obstructed room actually allow good ventilation through its interior, with wind velocity going as high as 3 kmph on a day when outside wind velocity was 1.2 – 3.5 kmph.

The roof is covered with conical terracotta tiles, known as Roman tiles. These tiles are placed on split bamboo purlins placed on timber truss. This roof covering provides better insulation from water, but thermal insulation reduces when compared to thatch.

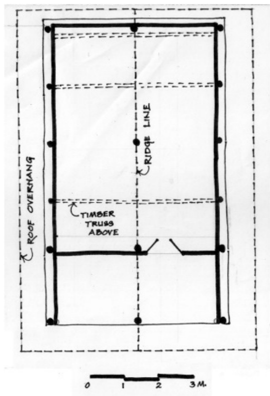

Fig. 7. Plan of Ghotul

7.4. Rathwa House, Vadodara, Gujarat

Houses of Rathwa type is intriguing because of the fact that the structure is distinctly divided into two portions – one half of it enclosed with porous mat wall, while the other having opaque mud wall. These two portions are covered with two independent sloped roofs which makes their juncture above the passage running through the centre of the house. Rathwas have a strong heritage of wall painting, and the semi-enclosed area has the entire mud wall beautifully painted.

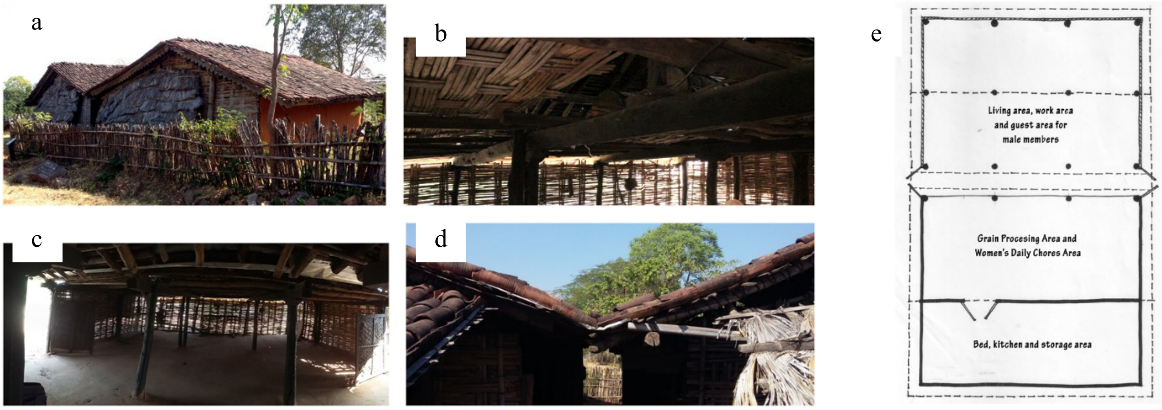

Fig. 8. (a) Twin hut form of Rathwa House, (b) Double roof and loft, (c) The seating area, (d) Junction of roof eaves. (e) Plan

The transparent skin of the work area is made of split bamboo mats. The structural system of the house is post-and-truss with connecting beams – all made of timber. Roof covering is done with clay tiles. In some ancillary sheds, such as bullock cart shade, worshipping shed, drinking water pot shed, that are kept outside the house – thatch roof is used.

The mud wall is a composite skin having very less thickness (100 mm). It is made by applying mud paste on bamboo mats. In the semi enclosed women's work area, the wall is only 75 mm thick, with mud paste applied only on the innder side of the bamboo mat. In the bed and kitchen room, the wall gets thicker after application of mud on both sides of the mat.

Fig. 9. Varied wall systems of Rathwa house

Fig. 10. The intricately painted semi-private cooking area

To increase the thermal insulation of the interior in an utilitarian way, Rathwas have lofts in their huts. Construction of these lofts is easily done by placing timber planks on the post-and-beam support system of the house.

7.5. Gadba House, Koraput, Gujarat

Gadba tribe is one of the oldest tribes of India settled in the coastal Koraput area of Orissa. Their earlier tradition had only circular houses in practice, although they have included rectangular huts in their vernacular form. The

museum premises have two shelters built by Gadba people – a circular hut with conical roof and a rectangular hut with conventional sloped roof.

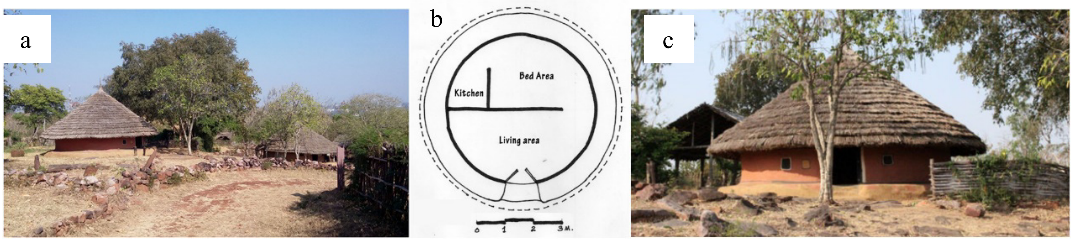

Fig. 11. (a) View of Gadba hut cluster, (b) Plan of circular Gadba hut, (c) View of circular hut

The circular hut is a compact unit of 17 feet diameter, having only a small door as opening. Like other tribes of India, Gadbas also have the practice of painting their external walls. However, an unique practice of painting window openings on opaque wall marks their hut out. The circular plan, coupled with the reduced amount of opening, provides this house an excellent surface area versus volume ratio (S/V).

Fig. 12. (a) Plan of rectangular Gadba hut, (b) Front view of rectangular hut, (c) Rear view of the hut

Compared to the circular plan, the rectangular huts of Gadba tribe has large overhangs that extend up to a third of the span of their roof truss. This ensures largely shaded walls along the entire movement of sun throughout the day, even in the glaring dusk hours. This house, like its circular counterpart, has only one doorway and only painted windows.

These huts have walls made completely of mud. There is not mat infill or adobe construction adopted in these. The structural system however varies from circular to rectangular hut. The former has a central timber pole from which timber purlins radiate on all sides. These members rest on the outer wall for their structural support. Roof covering is done with thatch made from hay.

Fig. 13. (a) Interior view showing low height partition wall, (b) Roof structure with radiating members

The hut is divided into living and bed area by a low height mud wall. This hut has a loft system which also rests on this low wall. The rectangular building has its roof supported on the timber posts and not on the external wall. The posts are located all around the mud wall, making it similar to the Muria Ghotul.

This hut has a proper partition wall fitted with door. This wall divides the house into a living room and a bed room-cum-kitchen area. Above this wall in the middle and the peripheral walls rests the loft system, which is similar to the circular building. However, an unique feature of the rectangular Gadba hut is that they apply mud coat on the soffit of the timber planks and then paint them beautifully.

7.6. Open-wall and Semi-Enclosed Sheds

a

b


Fig. 14. (a) Open structure used as cart shade, (b) Semi-open shade used for pottery

Two semi-open shades have also been surveyed under this study. First of them is an open shade used for exhibiting bullock carts in the museum. The shade has been built by local bhil tribe with their materials and technique. Second one is a semi-open shade used for pottery workshop in the museum premises. This is also built by local bhil tribesmen.

7.7. Comparative Measurements of the houses under study

All the vernacular buildings described above has been measured and compared on their appearance and physical dimensions. Table 1 shows the comparative analysis of these huts, along with two other open and semi-open shades.

Table 1: Comparative descriptions of houses / structures under study

Sl. No	***Description of House / Rooms in them***	***Original Region***	***Type of Building Design***	***Material of Wall***	***Wall Thickness (in inches)***	***Material of Roof***	***Enclosed Courtyard Present***	***Max. Height (at ridge) (mm)***	***Min Height (at wall) (mm)***	***Max Dimension (mm)***	***Min Dimension (mm)***
1	**Santhal Hut (average climatic values)**	Jharkhand	Clustered Courtyard House	Mud wall	14	Hay on bamboo frame, supported by timber truss	Yes	-	-	-	-
	(a) Bed Room							3353	2566	6833	3023
	(b) Kitchen							2566	1905	6833	1473
	(c) Guest Room							3048	2010	2972	2184

Sl. No	***Description of House / Rooms in them***	***Original Region***	***Type of Building Design***	***Material of Wall***	***Wall Thickness (in inches)***	***Material of Roof***	***Enclosed Courtyard Present***	***Max. Height (at ridge) (mm)***	***Min Height (at wall) (mm)***	***Max Dimension (mm)***	***Min Dimension (mm)***
	(d) Rice husking shed							2337	1829	4242	1778
	(e) Cattle room							2337	1829	3353	1778
2	**Garo hut**	Meghalaya	Single Stilted Hut	Split bamboo mat screen	1	Straw or long grass cover on narrow bamboo frame, supported by bamboo or timber truss	No	-	-	-	-
	(a) Entry Porch							8340	5560	3480	1245
	(b) Ante room							8340	5560	3480	2616
	(c) Main room							7760	4980	6248	3480
	(d) Parent's room							7760	4980	3480	2438
	(e) Rear balcony							7760	4980	3480	1245
3	**Muria ghotul**	Chhattisgarh	Single Hut	Daub wall - mud blocks on bamboo mat	10	Clay tile (roman) cover on bamboo frame, supported by timber truss	No	3480	2591	6630	4700
4	**Rathwa House**	Gujarat	Singular Composite Structure	Part bamboo mat screen + Part composit	2 in mat screen wall; 6 in mud plastered mat	Clay tile cover on timber frame, supported by	No	-	-	-	-

Sl. N o	***Description of House / Rooms in them***	***Original Region***	***Type of Building Design***	***Material of Wall***	***Wall Thickness (in inches)***	***Material of Roof***	***Enclosed Courtyard Present***	***Max. Height (at ridge) (mm)***	***Min Height (at wall) (mm)***	***Max Dimension (mm)***	***Min Dimension (mm)***
				e wall of mud plaster on bamboo mat	wall	timber truss					
	(a) Open mat area							3251	1727	7468	5360
	(b) Food preparation clay area							3251	1727	7468	3708
	(c) Clay cooking area							3251	1727	7468	2997
5	**Gadba Hut - Circular**	Orissa	Single Hut	Mud wall	13	Hay cover on timber and split bamboo frame, supported around single timber pole	No	3708	1600	5309	5309
6	**Gadba Hut - Rectangular**	Orissa	Single Hut	Mud wall	11	Hay cover on timber and split bamboo frame, supported on timber frame	No	3240	2286	4928	1626
7	**Open cart hut**	Bhopal	Single Shed	No wall	0	Hay cover on split bamboo frame, supported by bamboo truss	No	3100	2210	8154	4877

Sl. No	Description of House / Rooms in them	Original Region	Type of Building Design	Material of Wall	Wall Thickness (in inches)	Material of Roof	Enclosed Courtyard Present	Max. Height (at ridge) (mm)	Min Height (at wall) (mm)	Max Dimension (mm)	Min Dimension (mm)
8	**Semi-enclosed pottery hut**	Bhopal	Single Shed	Lightly woven split bamboo screen wall	0.5	Hay cover on split bamboo frame, supported by bamboo truss	No	2337	1676	9220	4724

8. Comparative analysis of various houses and their performances

The following data were collected for each of these structures.

- Ambient Temperature
- Relative Humidity
- Air Velocity
- Wall Surface Temperature inside room
- Wall Surface Temperature outside room

For simple single cell structures, only one(01) set of data was collected. For houses with multiple rooms and cells, climatic data have been collected room-wise. These data were compared against the five criteria contributing to thermal comfort, viz,

- Surface Area to Volume Ratio
- Building Material
- Shading
- Ventilation
- Orientation

First, it was investigated whether these components at all influence thermal comfort and then how different buildings perform differently based on these values. However as there were no two buildings of same design put in different orientation, the study and comparison on this particular aspect could not be done objectively. Rather a subjective discussion on this was done.

8.1. Surface area to volume ratio

The ratio of S/V plotted against ambient temperature of the room is plotted in Table 2. The scatter diagram based on this data is given in the Fig 15 given thereafter.

Table 2: S/V Ratio and ambient temperature of huts

Sl. No	Name of Structure / Tribe	Suface Area/Volume	Ambient Temperature inside structure / room
1	Semi-enclosed pottery hut	0.53	26.5
2	Santhal Hut (average climatic values)	1.50	25.1
3	Garo Hut	1.48	26.6
4	Muria ghotul	0.73	26.8
5	Rathwa House	0.79	26.9

6	Gadba Hut - Circular	0.75	25.8
7	Gadba Hut - Rectangular	1.64	25.5

Analysis: For hot and humid climate, lesser the ratio of S/V better the performance of the building. Structures belonging to this climate are Santhal Hut (2), Garo Hut (3) and Muria Ghotul (4). Lesser ratio signifies more opening on the walls, which is essential for a proper cross ventilation of the rooms and a better thermal comfort.

- The Garo Hut qualifies this property for its diaphanous wall. Hence, its higher ambient temperature of 26.6 degree against its high surface versus volume ratio of 1.48 correlates with the theory.
- On the other hand, both the Muria Ghotul (0.73, 26.88C) and Santhal Hut (1.50, 25.18C) does not comply with their original design.
- The Ghotul, despite having lesser than satisfactory S/V ratio, has large openings towards the top of the house. This induces heat inside the building, making them hotter.
- On the other hand, the relative less amount of opening on the Santhal house keeps it cool despite having a high S/V ratio.

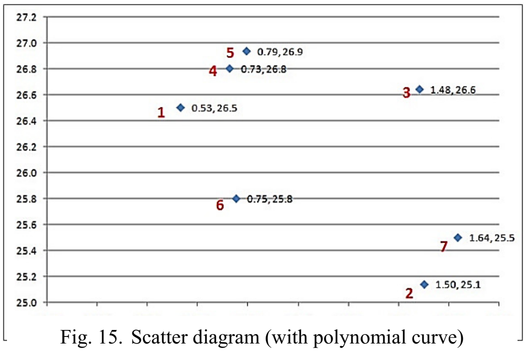

Fig. 15. Scatter diagram (with polynomial curve) showing S/V versus temp in 8C
(Number labels in red denote serial number in Table 2 above)

Similar observations can be found for the tropical wet and dry regions, to which the Gadba Huts of Orissa (6 & 7) belong.

- The circular hut, despite having lesser opening, has lesser perimeter of the wall and lesser surface area of the conical roof. The absence of opening allows it to perform well in this region also (0.75, 25.88C).
- The rectangular hut has much more surface area because of its geometry. However, the absence of opening helps it to give a better performance (25.58C) despite having the highest S/V ratio of 1.64.

On the contrary, for semi-arid regions, the more the ratio better the performance of the building due to lesser amount of opening. The pottery shed made by Bhils (1) and the Rathwa hut (5) both belong to this region.

- The pottery shed is enclosed only on three sides, and hence has a very low S/V ratio (0.53). Therefore, in this region it performed poorly with a temperature of 26.58C.
- The Rathwa hut also did not perform well due to its low S/V ratio of 0.79. In fact, it recorded the highest temperature among all the study huts with a 26.98C.

8.2. Building Material

Under the aspect of building materials, both wall material and roofing cover has been analysed separately. The difference between the inner and outer temperatures of the skin wall has been considered as an indicator to their performance. Table 3 and bar chart in Fig. 16 show the various wall materials and their thermal transmission scenarios.

Table 3: Wall materials and their performance in transmission of heat

Name of Structure / Tribe	Material of Wall	Wall Thickness (in inches)	Facing Sun			Opposite Sun		
			Skin Temp Inside	Skin Temp Outside	Diff in Temp	Skin Temp Inside	Skin Temp Outside	Diff in Temp
Santhal Hut (average climatic	Mud wall	14	23.3	28.1	4.8	23.3	25.4	2.1

Name of Structure / Tribe	Material of Wall	Wall Thickness (in inches)	Facing Sun			Opposite Sun		
			Skin Temp Inside	Skin Temp Outside	Diff in Temp	Skin Temp Inside	Skin Temp Outside	Diff in Temp
values)								
Garo hut	Split bamboo mat screen	1	27.9	31.6	3.7	26.4	29.5	3.1
Muria ghotul	Daub wall - mud blocks on bamboo mat	10	25.6	32.9	7.3	24.9	28.6	3.7
Rathwa House	Part bamboo mat screen + Part composite wall of mud plaster on bamboo mat	2 in mat screen wall; 6 in mud plastered mat wall	28.7	34	5.3	28.6	28.8	0.2
Gadba Hut - Circular	Mud wall	13	25.5	33.7	8.2	24	26.5	2.5
Gadba Hut - Rectangular	Mud wall	11	23.7	32.3	8.6	23.5	26	2.5

Analysis: In terms of absolute measure of thermal insulation, performance of pure mud wall is best, as it imitates the earth in terms of creating a non-conducting surface. Pure mud walls are found in the Gadba Huts of Orissa and the Santhal Huts of Jharkhand. These have fared best in terms of difference under direct sun, with a recorded difference as high as 8.6□C. Although Muria houses are adobe wall, ie, having mud layers on either side of bamboo mats, they have also performed well.

On the other hand, mixed walls like mat and mud wall or plain bamboo mat wall of Rathwa hut or the simple bamboo mat wall of Garo hut performed poorly in terms of thermal resistance. There is a huge difference in the Rathwa wall – the sun facing wall made of mat and mud has performed well, but the wall opposite sun, made of bamboo mats only, has performed poorest among all types of walls studied. On the other hand, the wall so fthe Garo hut, made of bamboo strips and flattened bamboo has performed poorly but consistently both facing sun and away from it.

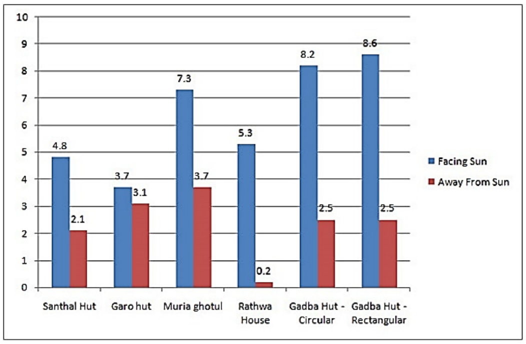

Fig. 16. Bar chart showing relative performances of walls facing and away from direct sunray

To analyse whether and to what extent thermal resistivity of a wall depends on its thickness, a Chi Square testing has been done. The hypothesis for the same was – "*Thermal Resistivity of a wall depends on its Thickness*". Following are tables 4 and 5for the same chi square analysis.

Table 4: Table of Observed Value of Difference in Temperature, Normalised for 10" wall thickness

Structure types	Difference for wall Facing Sun	Difference for wall Opposite to Sun	ROW TOTALS
Santhal Hut	3.4	1.5	4.9

Muria ghotul	7.3	3.7	11
Rathwa House	8.8	0.3	9.1
Gadba Hut - Circular	6.3	1.9	8.2
Gadba Hut - Rectangular	7.8	2.3	10.1
COLUMN TOTALS	33.6	9.7	43.3

Table 5: Table of Expected Value of Difference in Temperature

Structure types	Difference for wall Facing Sun	Difference for wall Opposite to Sun	ROW TOTALS
Santhal Hut	3.8	1.1	4.9
Muria ghotul	8.5	2.5	11
Rathwa House	7.1	2	9.1
Gadba Hut - Circular	6.4	1.8	8.2
Gadba Hut - Rectangular	7.8	2.3	10.1
COLUMN TOTALS	33.6	9.7	43.3

The Chi Square Value for the above two tables is 2.81 for a degree of freedom of (5-1)x(2-1)=4. We now refer to the following probability table based on chi square:

Table 6: Probability Table for Chi Square Values

Degrees of Freedom	Probability										
	0.95	0.90	0.80	0.70	0.50	0.30	0.20	0.10	0.05	0.01	0.001
1	0.004	0.02	0.06	0.15	0.46	1.07	1.64	2.71	3.84	6.64	10.83
2	0.10	0.21	0.45	0.71	1.39	2.41	3.22	4.60	5.99	9.21	13.82
3	0.35	0.58	1.01	1.42	2.37	3.66	4.64	6.25	7.82	11.34	16.27
4	0.71	1.06	1.65	2.20	3.36	4.88	5.99	7.78	9.49	13.28	18.47
5	1.14	1.61	2.34	3.00	4.35	6.06	7.29	9.24	11.07	15.09	20.52
6	1.63	2.20	3.07	3.83	5.35	7.23	8.56	10.64	12.59	16.81	22.46
7	2.17	2.83	3.82	4.67	6.35	8.38	9.80	12.02	14.07	18.48	24.32
8	2.73	3.49	4.59	5.53	7.34	9.52	11.03	13.36	15.51	20.09	26.12
9	3.32	4.17	5.38	6.39	8.34	10.66	12.24	14.68	16.92	21.67	27.88
10	3.94	4.86	6.18	7.27	9.34	11.78	13.44	15.99	18.31	23.21	29.59
	Nonsignificant								Significant		

Source: http://faculty.southwest.tn.edu/jiwilliams/probab2.gif

The probability of the hypothesis to be true is 70% for Chi Square value of 2.20, and the probability is 50% for Chi Square value of 3.36. By interpolating, we get the probability for the hypothesis to be true as 60%.

Thus we can conclude that the hypothesis "*Thermal Resistivity of a wall depends on its Thickness*" holds true to some extent. Rest would depend on other factors by which these buildings differed to a great extent.

8.3. Shading Devices

The foremost role played by shading device is to lower the temperature of the outer surface of the external wall. This in turn reduces the heat transmission through the wall, as the extent of such transmission depends on the difference of temperature between the internal and external surfaces.

The comparison of extent of shading has been done in terms of the roof overhang each of these building types has. Data on the same is furnished below in Table 7.

Table 7: Roof overhang vis-a-vis Temperature difference on external wall

Structure Types	Roofing Material	Roof Overhang (mm)	Temp. Of Exposed Wall □C	Temp. Of Shaded Wall □C	Difference in Temp. □C
Santhal Hut	Hay thatch	600	28.1	27.3	0.8
Garo hut	Grass thatch	875	31.6	29.5	2.1
Muria ghotul	Clay tile	675	32.9	28.6	4.3
Rathwa House	Clay tile	500	29.3	28.8	0.5
Gadba Hut - Circular	Hay thatch	875	33.7	26.5	7.2
Gadba Hut - Rectangular	Hay thatch	1575	32.3	23.2	9.1

The graphical representation of the data makes it evident that more the overhang of the roof, less is the thermal gain of the wall.

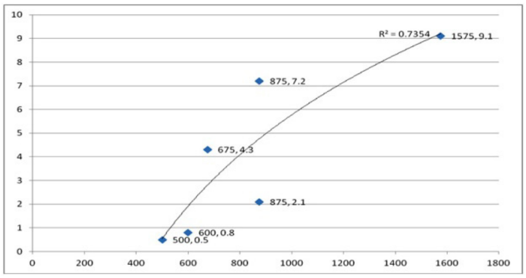

Fig. 17. Scatter diagram showing roof overhang in mm versus difference in temperature in 8C

8.4. Ventilation

The outdoor wind velocity was only 1.1 – 3.0 kmph. Inside the structures, following were some of the recorded wind velocities:

Table 8: Wind velocities recorded in-door

Structure Types	Wind velocities in kmph
Santhal Hut	0.3
Garo hut	0.1
Muria ghotul	2.4
Rathwa House	0.1
Gadba Hut - Circular	0.0
Gadba Hut - Rectangular	0.0

A subjective observation revealed that although there was considerable amount of heat inflow in the Muria Ghotul because of large openings near the roof, ambient temperature was lower than the outside temperature because of a strong wind movement.

Similar observations were perceived in the central courtyard of Santhal houses, where the above wind velocity was recorded.

8.5. Orientation

As stated in the opening paragraph of this section on data analysis, effect of orientation could not be observed as buildings of same / similar design were not available in multitude for disposal in different orientation.

9. Conclusion

The analysis and observation of data collected in the actual exhibit houses of the museum have revealed that the factors influencing thermal comfort of a building as laid out by Gupta and Chakraborty (2012) actually holds true to many extents.

The assumption that vernacular architecture of one climatic region may not perform equally efficiently in other regions was also probed, and was found true in many analysis.

However, there remains scope of further detailed research in this regard with larger sample sizes and data-sets for a more detailed analysis.

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